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B. Schwinn

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ON THE OCCURRENCE OF IONOSPHERE IRREGULARITIES IN THE F-LAYER

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by

V. N. Gershman

[USSR]

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ON THE OCCURRENCE OF IONOSPHERE IRREGULARITIES IN THE F-LAYER

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SUMMARY

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A

A new theory on ionosphere irregularity formations is proposed. This method is based on the drift flow instability of charged particles in the F-layer.

Author

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The investigation of ionosphere irregularities constitutes the subject matter of that particular section of physics called physics of the upper atmosphere layers. An abundant experimental material has been assembled during the past decade with respect to velocites, electron concentration, dimensions and lifetime of ionosphere irregularities. This material was systematized in several abstracts [1 - 5]. The nature of formation of these irregularities is still unknown, except for the E-region, where it is in the gas flow agitation mechanism, the latter playing the essential part of it. The irregularities appear as a result of turbulent mixing, and in the first approximation one can assume that during its motion the neutral component absorbs completely the ionized one.

The effectiveness of such mixing must, however, sharply decrease in passing to flows in the F-layer, which is first of all linked with

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the fact that at F-layer heights the appearance is made quite difficult on account of the great kinematic viscosities [4, 7]. Furthermore, it must be borne in mind that the movement of molecules in the F-layer in a direction perpendicular to the geomagnetic field (H_0) does not cause significant charged particle shift. Because of this, the mixing of electrons and ions is almost impossible.

It is necessary to point out that the above-described method of turbulent mixing is not the only one facing many difficulties. Such is also the case of other mechanisms brought forth to explain the origin of ionosphere irregularities in the F-layer and their nature [4, 7, 9]. In our opinion it is inappropriate to link, as was done earlier, the occurrence of irregularities in the F-layer with instabilities conditioned by the flow of neutral particles. It is necessary, first of all, to pay attention to the instabilities appearing during the electron and ion drifts. This statement will precisely be further developed during the discussion of the origin of irregularities with dimensions $l \sim 1 - 10$ km. We shall not discuss the nature of irregularities with dimensions $l \sim 100$ km

According to our theory, developed below, the causes for the occurrence of irregularities are as follows : first, the inhomogenous nature of electrons' and ions' drift in height and other directions (see details below) and, secondly, the presence of currents in the F-region of the ionosphere.

The conclusion about the appearance of small-scale structures in the magnetoactive plasma in the presence of currents was made earlier in a series of works for the purpose of its applications to gas-discharge [10] or high-temperature plasma [11]. The instability, then occurring, was not directly linked with the systems' boundary conditions and was called "convective current instability" [10].

In the chapter 1 below we shall obtain the conditions for the occurrence of instability in the drift motion, taking account of the situation arising in the F-layer. In the cases considered by us all the instabilities cannot be ascribed only to convective-current categories [10]. We established in chapter 2 the relationship between the instability conditions obtained in chapter 1 and the appearance of irregularities in the F-layer.

1. CAUSES OF INSTABILITY OF IONOSPHERIC DRIFT MOTIONS IN THE F-LAYER.

To determine the causes of instability appearance during flows of electrons and ions in the F-layer, it is necessary to conduct an investigation similar to that of [10].

The convective current instability in the plasma of the positive column in the presence of an outer magnetic field (H_0) was investigated in the last work. Because of the specific ionosphere conditions and the necessity of a series of simplifications, we are not in a position to use the results of [10] for our purpose. Therefore, we are forced to conduct a complete investigation, though in a condensed form. For the description of ionospheric plasma processes we will use the quasi-hydrodynamic systems of equations defining the flow of electrons and ions and the variation of their concentrations [4, 7, 10]

$$\rho_e \frac{\partial \mathbf{u}_e}{\partial t} + \rho_e (\mathbf{u}_e \nabla) \mathbf{u}_e + \rho_e \nu_{ei} (\mathbf{u}_e - \mathbf{u}_i) + \rho_e \nu_{em} (\mathbf{u}_e - \mathbf{u}_m) = -\nabla p_e + \eta_e \nabla^2 \mathbf{u}_e - \frac{eN_e}{c} [\mathbf{u}_e \mathbf{H}_0] - eN_e \mathbf{E}, \quad (1)$$

$$\rho_i \frac{\partial \mathbf{u}_i}{\partial t} + \rho_i (\mathbf{u}_i \nabla) \mathbf{u}_i + \rho_e \nu_{ei} (\mathbf{u}_i - \mathbf{u}_e) + \rho_i \nu_{im} (\mathbf{u}_i - \mathbf{u}_m) = -\nabla p_i + \eta_i \nabla^2 \mathbf{u}_i + \frac{eN_i}{c} [\mathbf{u}_i \mathbf{H}_0] + eN_i \mathbf{E}, \quad (2)$$

$$\frac{\partial N_e}{\partial t} + \operatorname{div}(N_e \mathbf{u}_e) = 0, \qquad \frac{\partial N_i}{\partial t} + \operatorname{div}(N_i \mathbf{u}_i) = 0. \quad (3)$$

Here ρ_e and ρ_i are the densities of electron and ion components; $\mathbf{u}_e$ and $\mathbf{u}_i$ are the velocities of regulated electron and ion flows; p_e and p_i are the partial pressures; η_e and η_i are the dynamic viscosities; $\mathbf{u}_m$ is the flow velocity of molecules; $\nu_{ei}, \nu_{em}, \nu_{im}$ are the numbers of collisions of electrons with ions and molecules, and of ions with molecules; N_e and N_i are the concentrations of electrons and ions respectively; $\mathbf{E}$ is the electric field; e is the absolute magnitude of the charge of an electron.

We shall firther consider that the conditions for plasma neutralization are fulfilled with a sufficient precisiOn and we assume that $N_e = N_i = N$. It is well known that the deflection from neutrality is very small if the frequency of disturbances $\omega \ll \omega_{0i}$, where ω_{0i} is the Langmuir frequency of plasma ions [12]. This inequality is fulfilled in cases of interest to us. At the same time, it is impossible to disregard the electric fields appearing at charge splitting. Such fields can be very significant even at weak splittings. With the aid of equations (1) — (3) we shall investigate small disturbances. For the purpose of such investigation we will assume that the electron and ion velocities $\mathbf{U}_{e0}$ and $\mathbf{U}_{i0}$ are given. It is essential, that subsequently we shall always consider $\mathbf{U}_{e0} \neq \mathbf{U}_{i0}$. Thus, in equilibirium conditions, the current density is $j_0 = eN_0 (\mathbf{U}_{i0} - \mathbf{U}_{e0}) \neq 0$. Let us divide the expression (1) by the density $\rho_e = mN$, and (2) by $\rho_i = MN$ (m and M being the masses of electrons and ions; for the sake of simplicity we shall consider that there are ions of only one kind). After linearization, we arrive at the following equations:

$$\frac{\partial \mathbf{u}_e'}{\partial t} + (\mathbf{u}_e'\nabla)\,\mathbf{U}_{e0} + (\mathbf{U}_{e0}\nabla)\,\mathbf{u}_e' + \nu_{em}\mathbf{u}_e' + \nu_{ei}(\mathbf{u}_e' - \mathbf{u}_i') = - \frac{\varkappa T_{e0}}{\rho_{e0}}\nabla N' + \frac{\varkappa\nabla(T_{e0}N_0)}{\rho_{e0}^2}\rho_e' + \bar{\nu}_{e0}\nabla^2\mathbf{u}_e' - \frac{e}{mc}[\mathbf{u}_e'\mathbf{H}_0] + \frac{e}{m}\nabla\varphi' \quad (4)$$

$$\frac{\partial \mathbf{u}_i'}{\partial t} + (\mathbf{u}_i'\nabla)\,\mathbf{U}_{i0} + (\mathbf{U}_{i0}\nabla)\,\mathbf{u}_i' + \nu_{im}\mathbf{u}_i' + \frac{m}{M}\nu_{ei}(\mathbf{u}_i' - \mathbf{u}_e') = - \frac{\varkappa T_{i0}}{\rho_{i0}}\nabla N' + \frac{\varkappa\nabla(T_{i0}N_0)}{\rho_{i0}^2}\rho' + \bar{\nu}_{i0}\nabla^2\mathbf{u}_i' + \frac{e}{Mc}[\mathbf{u}_i'\mathbf{H}_0] - \frac{e}{M}\nabla\varphi'. \quad (5)$$

In these and in the above-mentioned equations the unperturbed values values are provided with the index zero, and the perturbed ones with a dash. In passing from (1), (2) to (4), (5), we uti-lized the correlations $p_e = N\varkappa T_e$ and $p_i = N\varkappa T_i$ ($\varkappa$ being the Boltzmann constant and T the temperature). It was subsequently taken into account that at

$N_m \gg N$ (N_m being the concentration of molecules) it is possible to neglect the effect of charged particles on the neutral ones. Only sufficiently large-scale motions, commensurate with the dimensions of the F-layer, which are not discussed here, could constitute an exception. In (4) and (5) $\bar{\nu}_{e0}$ and $\bar{\nu}_{i0}$ are the kinematic viscosities for the electron and ion components. By order of magnitude $\bar{\nu}_{e0} \sim v_e^2/\nu_{em}$ and $\bar{\nu}_{i0} \sim v_i^2/\nu_{im}$, where v_e and v_i are the mean thermal velocities of flow for electrons and ions.

The electrostatic field $\mathbf{E} = -\bar{\nabla}\varphi'$, hindering a strong apliting of charges in the plasma, is introduced in (4) and (5). We were compelled to deal with such types of fields in numerous cases (for example in [10, 12, 13]. The method used by us, which takes into account the effect of electric fields, was borrowed from [10].

After lineralization the equations (3) can be written in the form

$$\frac{\partial N'}{\partial t} + N_0 \operatorname{div} \mathbf{u}_e' + N' \operatorname{div} \mathbf{U}_{i0} + \mathbf{u}_e'\nabla N_0 + \mathbf{U}_{e0}\nabla N' = 0, \tag{6}$$

$$\frac{\partial N'}{\partial t} + N_0 \operatorname{div} \mathbf{u}_i' + N' \operatorname{div} \mathbf{U}_{i0} + \mathbf{u}_i'\nabla N_0 + \mathbf{U}_{i0}\nabla N' = 0. \tag{7}$$

Considering that all the variables depend on time in accord with the law $i\omega t$, we obtain after some neglects :

$$\begin{aligned}
&[i\omega + (\mathbf{U}_{e0}\nabla) + \nu_e]\,\mathbf{u}_e' + \omega_H[\mathbf{u}_e'\tau] - \nu_{ei}\mathbf{u}_i' = \\
&= \left[-\frac{\varkappa T_{e0}}{\rho_{e0}}\nabla + \frac{m\varkappa}{\rho_{e0}^2}\nabla(N_0T_{e0})\right]N' + \frac{e}{m}\nabla\varphi', \\
&[i\omega + (\mathbf{U}_{i0}\nabla) + \nu_{im}]\,\mathbf{u}_i' - \Omega_H[\mathbf{u}_i'\tau] - \frac{m}{M}\nu_{ie}\mathbf{u}_e' = \\
&= \left[-\frac{\varkappa T_{i0}}{\rho_{i0}}\nabla + \frac{M\varkappa}{\rho_{i0}^2}\nabla(N_0T_{i0})\right]N' - \frac{e}{M}\nabla\varphi',
\end{aligned} \tag{8}$$

$$\begin{aligned}
&[i\omega + (\mathbf{U}_{e0}\nabla) + \operatorname{div}\mathbf{U}_{e0}]\,N' + [N_0\operatorname{div} + \nabla N_0]\,\mathbf{u}_e' = 0 \\
&[i\omega + (\mathbf{U}_{i0}\nabla) + \operatorname{div}\mathbf{U}_{i0}]\,N' + [N_0\operatorname{div} + \nabla N_0]\,\mathbf{u}_i' = 0.
\end{aligned} \tag{9}$$

In (8) τ is a unitary vector in the direction of the Earth's magnetic field $\mathbf{H}_0$;

$$\omega_H = \frac{eH_0}{mc}, \quad \Omega_H = \frac{eH_0}{Mc}$$

are the gyrofrequencies for electrons and ions ; $\nu_e = \nu_{em} + \nu_{ei}$.

We dropped the addends reflecting the effect of viscosity forces, for this is possible whenever the conditions

$$\nu_{em} \gg \bar{\nu}_{e0}k^2, \quad \nu_{im} \gg \bar{\nu}_{i0}k^2. \tag{10}$$

are fulfilled.

These inequalities imply that the wavelength $\lambda = 2\pi/k$ (or to be more precise — the length $l = \lambda/2\pi$). Below the F-layer maximum these conditions are fulfilled, but with not too great a reserve, for irregularities with $l \sim 5 \cdot 10^4 - 10^5$ cm (it is assumed that $l \sim \lambda$). Further, addends of the type $(\mathbf{u}_e'\nabla)\mathbf{U}_{e0}$ and $(\mathbf{u}_i'\nabla)\mathbf{U}_{i0}$, which are small by comparison with the terms $\nu_{em}\mathbf{u}_e'$ and $\nu_{im}\mathbf{u}_i'$, are neglected.

In order to obtain the dispersion equation and determine the conditions of perturbation accretion it is appropriate to write the equations (8) in projection on coordinate axes, choosing the axis z in the direction of the permanent magnetic field H_0. Subsequent simplifications will be to a great extent linked with the use of the condition

$$\Omega_H \gg \nu_{im}. \tag{11}$$

The limitation of (11) is quite specific for the F-layer and it determines the possibility itself of occurrence in the presence of lateral electric fields of elctrons' and ions' drift shiftings. At the fulfillment of the condition (11), we may admit with a still greater precision $\omega_H \gg \nu_{em}$. Projecting the equations (8) on the axis z and resolving them relative to variables u'_{ez} and u'_{iz}, we obtain

$$u_{ez} = \frac{A_{ez}}{\nu_e}, \quad u_{iz} = \frac{A_{iz} + \frac{\nu_{ei}}{\nu_e}\frac{m}{M}A_{ez}}{\nu_{im}}, \tag{12}$$

where A_{ez} and A_{iz} are determined by the formulas

$$A_{ez} = \left[-\frac{\varkappa T_{e0}}{\rho_{e0}}\frac{\partial}{\partial z} + \frac{m\varkappa}{\rho_{e0}^2}\frac{\partial}{\partial z}(N_0T_{e0})\right]N' + \frac{e}{m}\frac{\partial\varphi'}{\partial z},$$

$$A_{iz} = \left[-\frac{\varkappa T_{i0}}{\rho_{i0}}\frac{\partial}{\partial z} + \frac{M\varkappa}{\rho_{i0}^2}\frac{\partial}{\partial z}(N_0T_{i0})\right]N' - \frac{e}{M}\frac{\partial\varphi'}{\partial z}. \tag{13}$$

In order to obtain (12) and (13) it was necessary to assume that $\omega \ll \nu_e$, $\omega \ll \nu_{im}$ and drop a series of addends, whose smallness stems from the preceding inequalities. To simplify further we will neglect the addend with $\frac{\nu_{ei}}{\nu_e}\frac{m}{M}A_{ez}$

in the correlation for u'_{iz} (12). Usually $\nu_{em} > \nu_{ei}$. below the F-layer maximum. Then the accounting of this addend has no decisive significance for the conclusions even at $\nu_{em} \sim \nu_{ei}$.

For velocity components of a direction transverse to thefield H_0 after taking into account (11) and a series of inequalities of evident character, we have

$$u'_{ex} = -\frac{1}{\omega_H}A_{ey}, \quad u'_{ix} = \frac{1}{\Omega_H}A_{iy}, \quad u'_{ey} = \frac{1}{\omega_H}A_{ex}, \quad u'_{iy} = -\frac{1}{\Omega_H}A_{ix}.$$

The writing rules of the correlations $A_{ex}, A_{ey}, A_{ix}, A_{iy}$ are clear from (13). Further, it is necessary to find the mathematical expression for $\operatorname{div}\mathbf{u}_e'$, $\operatorname{div}\mathbf{u}_i'$ $\nabla N_0\mathbf{u}_e'$, $\nabla N_0\mathbf{u}_i$ and substitute correspondingly in (9). Subsequent analysis shows, however, that for the purpose of preliminary abalysis many terms can be neglected. In order to save space we will show in detail the possibility of rejecting a series of small terms offering no interest for the question of ionosphere irregulatity occurrence. We shall neglect the terms $\sim 1/\omega_H$, and also, respectively the addends of the order $1/\Omega_H^2$ and $1/\Omega_H$. This neglect formally responds to the transitions $u_{e,xy} \to 0$ and $u_{i,xy} \to 0$.

Here it must be borne in mind, that by dropping the terms $1/\omega_H^2$, $1/\Omega_H^2$, we fully neglect the contribution from the transverse diffusion (diffusion in a direction perpendicular to H_0). The coefficient of such a diffusion in the F-layer is much less than the longitudinal one. For flat-wave disturbances the transverse diffusion may become determinant if the direction of the distribution constitutes an angle near $\pi/2$ with H_0. But for our calculations we shall further assume that such peculiar type of conditions do not take place, and the main contribution is thus provided by the longitudinal diffusion.

In the second place, neglecting the terms $\sim 1/\omega_H$ is tantamount to failing to account for the conective-current instability mechanisms which were the object of investigations in [10] and in a number of other papers.

After a few modifications in the formulas (9), (12), (13) we will obtain the formulas (14) and (15) hereafter :

$$\left[i\omega + (\mathbf{U}_{e0}\nabla) + \operatorname{div} \mathbf{U}_{e0} - \frac{\varkappa T_{e0}}{m\nu_e}\frac{\partial^2}{\partial z^2} + \frac{2\varkappa T_{e0}}{m\nu_e}\frac{\partial \ln N_0}{\partial z}\frac{\partial}{\partial z}\right] N' + \\ + \frac{eN_0}{m\nu_e}\left[\frac{\partial}{\partial z} + \frac{\partial \ln N_0}{\partial z} - \frac{\partial \ln \nu_e}{\partial z}\right]\frac{\partial \varphi'}{\partial z} = 0, \tag{14}$$

$$\left[i\omega + (\mathbf{U}_{i0}\nabla) + \operatorname{div} \mathbf{U}_{i0} - \frac{\varkappa T_{i0}}{M\nu_{im}}\frac{\partial^2}{\partial z^2} + \frac{2\varkappa T_{i0}}{M\nu_{im}}\frac{\partial \ln N_0}{\partial z}\frac{\partial}{\partial z}\right] N' - \\ - \frac{eN_0}{M\nu_{im}}\left[\frac{\partial}{\partial z} + \frac{\partial \ln N_0}{\partial z} - \frac{\partial \ln \nu_{im}}{\partial z}\right]\frac{\partial \varphi'}{\partial z} = 0. \tag{15}$$

In passing to (14) and (15) we dropped the terms containing the product of derivatives from regular quantities (for example the addends

$$\sim \frac{\partial N_0}{\partial z} \times \frac{\partial T_{e0}}{\partial z}$$

and others.). Let us further note that the terms with $\frac{\partial N_0}{\partial z}\frac{\partial N'}{\partial z}$ in (14), (15) may also be dropped, inasmuch as they exert a small effect on the propagation velocity of perturbations. For the flat-type disturbances all these terms are in phase with the true part of the complex frequency ω. But for our purpose, however, the main interest resides in the determination of perturbations' accretion velocity (rate).

The variable φ' can obviously be eliminated from (14), (15). At the same time, neglecting the small terms of the order of those already dropped, we arrive at the following equation :

$$\frac{\partial}{\partial z}\left\{\frac{M\nu_{im}}{eN_0}\left[i\omega + (\mathbf{U}_{i0}\nabla) + \operatorname{div} \mathbf{U}_{i0} - D_i\frac{\partial^2}{\partial z^2}\right] N' + \right. \\ \left. + \frac{m\nu_e}{eN_0}\left[i\omega + (\mathbf{U}_{e0}\nabla) + \operatorname{div} \mathbf{U}_{e0} - D_e\frac{\partial^2}{\partial z^2}\right] N'\right\} + \frac{\partial \ln N_0}{\partial z}\left\{\frac{M\nu_{im}}{eN_0}[i\omega + (\mathbf{U}_{i0}\nabla)] + \right. \\ \left. + \frac{m\nu_e}{eN_0}[i\omega + (\mathbf{U}_{e0}\nabla)]\right\} N' + \frac{\partial \ln \nu_e}{dz}\left\{\frac{M\nu_{im}}{eN_0}[i\omega + (\mathbf{U}_{i0}\nabla)] N'\right\} - \\ - \frac{\partial \ln \nu_{im}}{\partial z}\left\{\frac{m\nu_e}{eN_0}[i\omega + (\mathbf{U}_{e0}\nabla)] N'\right\} = 0. \tag{16}$$

In (16) $D_e = \varkappa T_{e0}/(m\nu_e)$ and $D_i = \varkappa T_{i0}/(M\nu_{im})$ have a dimensionality of diffusion coefficients. When finding the conditions of perturbation accretion we shall eliminate in the first approximation the dissipative processes and the processes which may lead to instability, neglecting in (16) the terms with $\partial \ln N_0/\partial z$, $\partial \ln \nu_e/\partial z$ and $\partial \ln \nu_{im}/\partial z$, and dropping also the diffusion terms and the addends with div U_{e0} and div U_{i0}. We then obtain

$$\{M\nu_{im}[i\bar{\omega} + (\mathbf{U}_{i0}\nabla)] + m\nu_e[i\bar{\omega} + (\mathbf{U}_{e0}\nabla)]\}N' = 0. \tag{17}$$

According to (17), we notice that further on, the frequency ω is considered complex

$$\omega = \bar{\omega} - i\gamma, \tag{18}$$

where $\bar{\omega}$ and γ are true, If $\gamma > 0$, the small perturbations grow in time according to the law $e^{\gamma t}$. If the velocities U_{e0} and U_{i0} vary little over the wavelength, flat waves may be utilized for solutions of (17), assuming that N' varies according to the law $\exp(-i\mathbf{kr})$. Then, we obtain from (17) the equality

$$M\nu_{im}(\bar{\omega} - k\mathbf{U}_{i0}) + m\nu_e(\bar{\omega} - \mathbf{k}\mathbf{U}_{e0}) = 0. \tag{17a}$$

Considering that the velocities U_{e0} and U_{i0} do not differ much from one another, and are at any rate of the same order, we get approximately from (17a)

$$\bar{\omega} \approx \mathbf{k}\mathbf{U}_{i0}. \tag{19}$$

In passing to (19) it was taken into account that in the F-region of the ionosphere $\nu_e \sim \nu_{em}$, by the strength of what $M\nu_{im} \gg m\nu_e$.

In the next approximation, assuming that $\gamma \ll \omega$, and taking into account (17a), (19), we reach the following correlation:

$$\gamma = -\operatorname{div}\mathbf{U}_{i0} - D_i\left(1 + \frac{T_{e0}}{T_{i0}}\right)k_z^2 + \left(\frac{\partial \ln \nu_e}{\partial z} - \frac{\partial \ln \nu_{im}}{\partial z}\right)\frac{m\nu_e}{M\nu_{im}}\frac{(\mathbf{k}\mathbf{j}_0)}{eN_0k_z}. \tag{20}$$

Here $\mathbf{j}_0 = eN_0(\mathbf{U}_{i0} - \mathbf{U}_{e0})$ is the current density. Formula (20) is final and use of it is going to be made in the next chapter.

2.- INSTABILITY OF DRIFT MOTIONS AND IRREGULARITY FORMATION IN THE F-LAYER OF THE IONOSPHERE.

Let us apply the drift motion instability criterion obtained in chapter 1, to the interpretation of the phenomenas connected with the appearances of ionospheric irregularities in the electron concentration. It is fairly evident that to form inhomogeneities or irregularities the condition of weak disturbance accretion is prerequisite. Further, we shall compare the drift of inhomogeneities with the propagation of waves, whose velocities $V_\Phi = (\bar{\omega}/k^2)\mathbf{k}$ are determined from (19), and the accretion (damping)— from (20)

Note, that in literature one can find indications on the wave-like shift of the irregularities with an expressed vibration monochromaticity [14]. However, the conclusions on the occurrence of inhomogeneities can be applied also to cases with vibration monochromaticity less sharply expressed. One may assume that the principle of superimposition is valid at irregularity appearance and the electron density variations may be interpreted as a result of concomitance of traveling wave propagation. At the same time it is essential that increments do not depend directly on the frequency

The absolute value of phase velocity V_Φ can be determined from the correlation

$$V_\Phi = U_{i0} \cos\theta, \tag{21}$$

provided we refer to (19). Here is the angle between the direction of the shift velocity of ions $\mathbf{U}_{i0}$ and the wave vector $\mathbf{k}$. The selection of non-damping disturbances make it necessary to limit ourselves to waves with a small vector $\mathbf{k}$ component in the direction of the field H_0. Otherwise, the role of longitudinal diffusion would have been so subtantial that there could be no question of true wave accretion. Therefore we shall postulate that $k_x \gg k_z$ or $k_y \gg k_x$. (see below).

As to the true irregularities, we always have to do with certain specific assortments of waves (wave packs). In such cases it is more correct to link the irregularity shift with the group velocity $V_{rp} = \partial\omega/\partial k.$ rather than with the phase velocity. From (19), we have

$$V_{rp} = U_{i0}, \qquad (22)$$

i.e. the shift velocity of the nonuniform structure is defined by the regulated ion velocity. However, an essential remark must be made that the waves with large components k_z damp vigorously. Essentially, the perturbations propagating in a quasitransverse direction relative to H_0 will either be essentially weakly-damping or non-damping at all. If the shift of ions along H_0 is determined by the motion of the neutral component [4, 7], then in the directions perpendicular to H_0 drift-type shifts, occurring for instance under tht effect of lateral electrostatic fields, play an essential part. It is clear from the above-said, that in the given case we may approximately estimate that

$$V_{rp} = U_{i0\perp}, \qquad (22a)$$

where $U_{i0\perp}$ is the transverse component of the velocity U_{i0}.

Thus, we reach the conclusion that at appearance of irregularities the velocity of wave motions in the F-layer is determined by the drift-component. In the first approximation the component U_{i0} does not exert any effect on the motion of irregularities in our interpretation. Insamuch as in reality we have to do with wave packs rather than with waves proper, only an estimate for the velocity of the type – $V_{rp} \sim \omega/k \approx \lambda/T$, where is the wavelength and T– the oscillation period, can be given, The length is considered to be of the same order with the characteristic dimension of the irregularities . From the estimate thus brought out it is clear, that for a fixed velocity of motion to irregularities of greater scales correspond greater oscillation periods. As far as can be judged, this conclusion corresponds to reality.

Let us now pass to the basic questionof wave accretion and damping. According to (20) we have

$$\gamma = \gamma_D + \gamma_1 + \gamma_2, \qquad (23)$$

where

$$\gamma_D = -D_i\left(1+\frac{T_{e0}}{T_{i0}}\right)k_z^2 = -\frac{\varkappa(T_{e0}+T_{i0})}{M\nu_{im}}k_z^2 = -D_{\parallel}k_z^2,$$

$$\gamma_1 = -\operatorname{div}\mathbf{U}_{i0}, \quad \gamma_2 = \left(\frac{\partial \ln \nu_e}{\partial z} - \frac{\partial \ln \nu_{im}}{\partial z}\right)\frac{m\nu_e}{M\nu_{im}}\frac{(\mathbf{kj}_0)}{eN_0k_z}.$$

The first addend in (23) defines the damping of disturbances ($\gamma_D < 0$) on account of the longitudinal ambipolar diffusion. The quantities γ_1 and γ_2 may be, generally speaking, positive as well as negative.

Let us consider first of all the effect of diffusion. For $\gamma_D = -Dk^2(k_z^2/k^2)$ it is essential as to how the relation k_z/k is chosen. It is however clear that the condition $k_z \ll k$ must be admitted. For example, at 250 km altitude the value $D_{\parallel} \sim 7 \cdot 10^9$ cm^2/sec [13]. Then, at $l \sim \lambda \sim 1$ км the value $\gamma_D \sim 30(k_z^2/k^2)$. The irregularity lifetime $t_D \approx 1/\gamma_D$ at $k_z \sim k$ would be very short and would only constitute $t_D \sim 10^{-1} - 10^{-2}$ sec, which does not correspond to reality. At $k_z/k \sim 10^{-2}$ we obtain $t_D \sim 10^2 - 10^3$ sec, which already is acceptable. From that example and from other estimates, which at the the present stage of development of the theory bear only a qualitative character, it follows that at $k_z/k \sim 10^{-1} - 10^{-2}$ the value $\gamma_D \sim 10^{-2} - 10^{-3}$.

We shall show below, that γ_1 and γ_2 may be positive at specific assumptions and have values no smaller than $\gamma_D \sim 10^{-3}$, and at times even $\gamma_D \sim 10^{-2}$. This speaks of the possibility of disturbance accretion in the presence, however, of a favorable situation. The inequality implies that at irregularity appearance the horizontal component of their velocities must have for the basic component either the east-west or the west-east one. The predominating occirrence of this component is the result of experience [14, 15]. At the same time, one should remember that our assertions refer only to the generation region and that they do not imply at all that either the east-west or west-east component must be prevailing at all observations. In the discussions above we did not make any distinction in the rough approximation between the geographic and geomagnetic coordinates.

The addend $\gamma_1 = -\operatorname{div} U_{i0}$ is different from zero in the presence of regular variations of ion velocities U_{i0} in space. The character of these variations for the drift component $U_{i0\perp}$ is still not quite clear. Another cause may reside in the neutral gas shifts along the field H_0, at which electron entrainment may take place with a velocity $U_{i0\parallel} = U_{mz}$, where U_{mz} is the z- component of molecule velocity. If we assume that vertical motions with a velocity $U_{mz} \sim 10^4$ cm/sec are possible, with the variations in the z and h directions of the same order, we have

$$\operatorname{div} U_{i0} = -\frac{\partial U_{mz}}{\partial z} \sim -\frac{\partial U_{mz}}{\partial h}.$$

The velocity U_{mz} must vary substantially over distances of the order of the height of the uniform atmosphere H. At $H = 4 \cdot 10^6$, the quantity

$$\frac{\partial U_{mz}}{\partial h} \sim \frac{U_{mz}}{H} \sim 2 \cdot 10^{-3} \ sec^{-1}$$

The obtained value γ_1 is comparable with the above-presented figures for γ_D, so that disturbance increase is possible if $\partial U_{mz}/\partial h < 0$. We must however admit that the admitted values of $U_{mz} \sim 10^4$ cm/sec are rather great. We may also point to a subsequent possible means of irregularity appearance of small-scale type. In the presence of drift the considered,echanism at $\operatorname{div} U_{i0} \neq 0$ may ensure in the first place the accretion of large-scale distur ances with $l \gtrsim 10$ km, since for them the weakening effect of diffusion is less significant. At sufficiently strong accretion irregularities in the velocity U_{i0} may occur, further leading to smaller-scale wave accretion. Over this path it is easy to explain the existence of some sort of an assortment of various-scale irregularities in the F-layer, which is often noted at observations.

The quantity γ_2 is different from zero only in the presence of currents with a density $j_0 = eN_0 (U_{i0} - U_{e0}) = eN_0 \Delta U_0$. It is beyond doubt that such currents exist in the dynamo-region below the F-layer. This supports the assumption of the existence of currents in higher regions. The dependence of γ_2 on j_0 is in correspondence with the experimentally established proportionality between the frequency of irregularity occurrence and the magnetic activity [2,14]. In estimating the value of γ_2 it is mecessary to bear in mind that the sign of kj_0 and the difference $\partial \ln \nu_e/\partial z - \partial \ln \nu_{im}/\partial z$ is immaterial, for at appropriate choice of $k_z > 0$ or $k_z < 0$, one may assure the positiveness of γ_2. We shall consider that by the absolute value of $\partial \ln \nu_e/\partial z - \partial \ln \nu_{im}/\partial z$ of the order of $\partial \ln \nu_e/\partial z \sim \partial \ln \nu_{im}/\partial z \sim 1/H$, i.e. the addends are not compensated in this difference. Assuming that $H \approx 4 \cdot 10^6$ cm at $m\nu_e/M\nu_{im} \sim 10^{-2}$, $\Delta U_0 \sim \beta U_{i0}$ and $U_{i0} \sim 5 \cdot 10^4$ cm/sec (during the period of magnetic activity), we have the estimate $\gamma_2 \sim 10^{-4} \beta \frac{k}{k_z}$. At $\beta \sim 1$ and $k/k_z \sim 10^{-2}$, the quantity $\gamma_2 \sim 10^{-2}$ sec^{-1}, i.e. $\gamma_2 \gtrsim \gamma_D$ (for the same k_z/k). In fact, however, the value of the velocity U_0 is less than that of U_{i0}, so that $\beta \leqslant 1$. At $\beta \approx 0{,}1$ the value $\gamma_2 \approx 10^{-3}$ sec^{-1} for the very same k/k_z, which also leaves a possibility of increase, particularly for for irregularities with $l \sim 1 - 2$ km. From these estimates it is clear, that the reinforcement mechanism may be effective in the F-layer at great currents, which probably are induced only during the periods of strong magnetic disturbances.

We shall point out in conclusion that the above estimates for γ_1 and γ_2 appear to be rough. The same may be said in respect to drift motion characteristics. Therefore, further work must be conducted with a better comparison of theory with practice. However, in the experimental field numerous data are unfortunately insufficiently specific. Certain precisions in the field of theory may possibly have to be effected. However, we hope that the basic idea of this work will result correct and fruitful for the understanding of the causes leading to irregularity appearance in the F-layer.

We shall stress once more, that in our opinion the cause of irregularity appearance in this region of the ionosphere resides in the instability of the drift flow of electrons and ions.

**** THE END ****

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Radiophysical Institute
at Gor'kiy State University, Gor'kiy USSR

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